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Multi-Criteria Evaluation of Manufacturing Systems 4.0 under Uncertainty

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Abstract

Introducing Manufacturing Systems 4.0 is essential for the existence of competing industrial companies. Nevertheless, knowledge about benefits of Manufacturing Solutions 4.0 is limited. This paper introduces an approach to evaluate Manufacturing Systems 4.0. Uncertainty is integrated via fuzzy set theory and stochastic models. The financial impact of non-monetary criteria is directly modelled. A Monte-Carlo Simulation aggregates criteria in a probability distribution of the projects net present value (NPV). Comparing distributions of different alternatives determines the most favorable alternative and analyses potential and risk. Through this concept understanding of Manufacturing Systems 4.0 is improved and their benefits are displayed comprehensively.

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Keywords: Manufacturing System 4.0; Manufacturing System Evaluation; Evaluation Uncertainty

1. Introduction

Dynamic markets with shortening lead times, increasing customer expectations and ever growing competition in a globalizing world force producing companies to improve their manufacturing systems. Such systems need to adapt autonomously, without failure and at the highest possible speed to changing requirements. Manufacturing Systems 4.0 achieve these goals through sensors, interconnectivity and automated intelligent controllers. Such manufacturing systems are also called Cyber-Physical Manufacturing Systems and even a strategic change of business models can be induced by such systems in order to increase for instance the focus on service offers and customer relations. [1]

Despite their importance, several barriers exist when introducing Manufacturing Systems 4.0. On the one hand, high investment cost are related to Manufacturing Systems 4.0. On the other hand, there is no clear vision and strategy on how to implement Cyber-Physical Manufacturing Systems. Additionally, the knowledge about the utilization and the benefits of these technologies is limited. [2]

Thus, this paper introduces an evaluation method which specifically concentrates on Manufacturing System 4.0. Uncertainty is considered within the method and quantitative and qualitative criteria are used as input data. The method will be used to model strategic implications of manufacturing systems in a comprehensive and transparent way.

2. Literature overview

The research about the evaluation of manufacturing systems is reviewed regarding the integration of strategic implications and uncertainty. Moreover, the use of qualitative criteria, complete financial evaluation, comprehensibility, transparency and flexibility is considered. The reviewed evaluation methods can be split into two categories.

The first category focuses on the comprehensibility and transparency aspect but lacks adequate uncertainty integration and the possibility of a complete financial evaluation. Rivera and Frank display the economic potential in cost time graphs and include improvements through material savings, cycle time acceleration and minimization of waiting time [3]. Gracanin et al. adapt cost time profiles to optimize value streams [4]. Searcy uses quantitative descriptors which are weighted via an analytical hierarchy process to evaluate the application of lean methods in manufacturing systems [5]. Sobczyk and Koch

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structure their method around a value stream model and evaluate the manufacturing system based on modules regarding cost, inventory, production resources, company financials and other company-specific factors [6]. Kolakowski et al. combine an utility analysis for non-monetary criteria and a net present value (NPV) calculation for all monetary or monetary-transformable criteria [7, 8]. Briel focuses on a key performance indicator (KPI) based analyses of adaption investments in manufacturing systems comprising system's life cycle [9]. Peter evaluates lean methods via modelling of impact chains corresponding to certain KPIs [10]. Niemann applies dynamic life cycle controlling to evaluate and optimize manufacturing systems through simulating system adaptions and benchmarking the cost per part against other alternatives [11]. Kirsch evaluates Manufacturing Systems 4.0 via scale-based surveys of qualitative criteria and compares their fulfillment with the financial advantages of the manufacturing solutions [12]. Winkler et al. aggregate and combine the overall equipment effectiveness (OEE) including time losses because of inventory and production processes with a similar logistic-focused indicator to display the overall efficiency of a manufacturing system [13].

The second category comprises methods which integrate uncertainty and result in a comprehensive financial evaluation. However, due to the complex modelling approach for financial impacts and uncertainty considerations comprehensibility, transparency and flexibility are not considered in an adequate way. Reinhart et al. simulate stochastic criteria in a Monte-Carlo Simulation. They consider market demand uncertainty in a decision tree and conduct the final evaluation in a cost model comprising both models mentioned earlier [14]. Consequently, Reinhart at. al combines the Monte-Carlo Simulation of quantitative criteria and the transformation of qualitative criteria in a fuzzy neuronal network to calculate a probability distribution of the NPV [15, 16]. Möller uses the real option pricing theory to evaluate the performance of manufacturing systems which are subjected to dynamic environments [17]. Wunderlich conducts simulation-based cost analyses, production process analyses and investment analyses under uncertainty to determine the advantages of manufacturing systems [18]. Jondral uses simulation-based cost time graphs in combination with utility analyses and NPV calculations for the evaluation of lean method applications in manufacturing systems [19]. Peters uses the backward induction solution of a Markov decision process based on OEE and Monte-Carlo Simulation of market demands to create an investment strategy for manufacturing systems under uncertainty [20].

In conclusion, the literature review displays that there are already evaluation methods in place. However, these methods can be split into two categories whereof neither category is able to fulfill all presented requirements. Furthermore, none of the mentioned previous work focuses on Cyber-Physical Manufacturing Systems. The method introduced in this paper focuses on the presented imbalance of complexity and comprehensibility throughout the analysed evaluation methods for manufacturing systems and particularly takes Manufacturing Systems 4.0 into account.

3. Evaluation method

The comprehensive evaluation of Manufacturing Systems 4.0 under uncertainty is crucial to maintain a competitive production system. The evaluation method has to be applied in the factory planning process depicted in Figure 1.

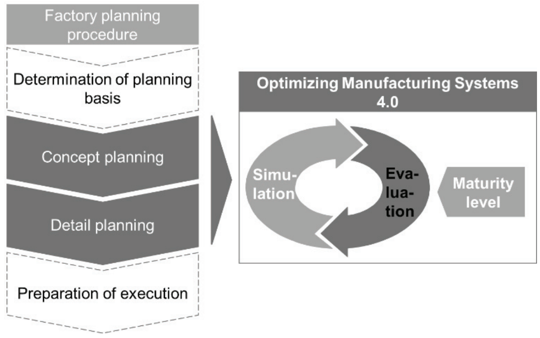

Fig. 1: Optimizing Manufacturing Systems 4.0

Especially the combination of real time based digital simulation and evaluation enables companies to iteratively enhance their factory plan with limited effort [21]. A maturity level model can be used to further adapt the evaluation to different technology standards.

The presented evaluation method consists of a five step approach and is illustrated in Figure 2.

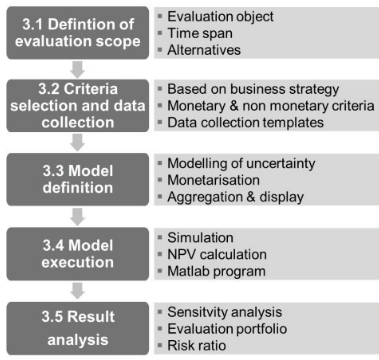

Fig. 2: The evaluation process

First, the evaluation scope consisting of the evaluation object, the time span and the alternatives is defined. Following this, non-monetary and monetary criteria are chosen based on the business strategy of the company and the collection of data is conducted, ideally using standardized templates. The subsequent definition of the evaluation model includes the modelling of uncertainty, monetary transformation of non-monetary criteria as well as the aggregation of criteria and the decision on how to display the results. Next, the model is executed in a simulation of the projects NPV. In this case a Matlab program is used for the calculations. Finally, the